

PRACTICE EFFECTS, EMOTION, AND MECHANISMS OF DUAL-TASK
INTERFERENCE IN DRIVING AND CELL PHONE RESEARCH

A Thesis
Presented to
The Academic Faculty

by

Erin Lightman

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science in the
School of Psychology

Georgia Institute of Technology
August, 2010

PRACTICE EFFECTS, EMOTION, AND MECHANISMS OF DUAL-TASK
INTERFERENCE IN DRIVING AND CELL PHONE RESEARCH

Approved by:

Dr. Eric H. Schumacher, Advisor
School of Psychology
Georgia Institute of Technology

Dr. Fredda Blanchard-Fields
School of Psychology
Georgia Institute of Technology

Dr. Paul Verhaeghen
School of Psychology
Georgia Institute of Technology

Date Approved: January 14, 2009

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Eric Schumacher for his guidance and encouragement with each step of the thesis process. I also thank the other members of my graduate committee, Dr. Fredda Blanchard-Fields and Dr. Paul Verhaeghen, for their advice and comments about how to improve the experiment and how to address the findings. Special thanks go to Zane Blanton for his central role in programming some of the more complicated tasks in this experiment. Thanks also go to Vijay Palvia for compiling the database for the verbal tasks, and to Rachelle Stevens-Carr, Gurlynn Singh, and Brittany Zimmerly for their help in preparing the data for analyses. Finally, I would like to thank the members of CoNTRoL for their support and advice.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii
SUMMARY	ix
<u>CHAPTER</u>	
1 CHAPTER 1: INTRODUCTION	1
1.1 Explanations for Interference	5
1.2 Computational Models of Dual-Task Interference	7
1.3 Limitations of Cell Phone and Driving Research	10
1.4 Mechanisms of Interference	13
1.5 Emotion Regulation	15
1.6 Ego Depletion Model	18
1.7 Current Experiment	19
2 CHAPTER 2: METHODOLOGY	21
2.1 Participants	21
2.2 Stimuli and Apparatus	21
2.3 Tasks and Design	21
2.4 Procedure	24
3 CHAPTER 3: RESULTS	27
3.1 Outlier Removal	27
3.2 Tracking	27
3.3 Paired Associates	29

3.4 Verb Generation	31
3.5 Session 6 and Session 7	32
4 CHAPTER 4: DISCUSSION	37
REFERENCES	46

LIST OF TABLES

	Page
Table 1: Mean Reaction Time Data for Verbal Tasks	34

LIST OF FIGURES

	Page
Figure 1: Tracking Data for Session 2 through Session 7	28
Figure 2: Paired Associate Reaction Time Data for Session 2 through Session 7	30
Figure 3: Paired Associate Accuracy Data for Session 2 and Session 6	31
Figure 4: Verb Generation Reaction Time Data for Session 2 through Session 7	32
Figure 5: Tracking Data for the Maintenance Control and Emotion Regulation Groups for Session 6 and Session 7	33
Figure 6: Paired Associate Reaction Time Data for Session 6 and Session 7	34
Figure 7: Self Report Data in Session 7	35

SUMMARY

Decades of research suggest that talking on a cell phone interferes with driving performance, but the underlying mechanisms of this interference remain poorly understood. Driving and cell phone research often generalizes easy, novice laboratory tasks to the well practiced task of driving, and it frequently ignores important factors like emotion in tasks used to represent cell phone conversation. This experiment sought to address these issues. Participants performed a tracking task and two verbal tasks over 7 one-hour sessions. At some times the tasks were performed individually, and at others the tracking task was performed concurrently with one of the verbal tasks. Participants watched an anger-inducing film clip at the beginning of the 7th session and were instructed to either down-regulate or maintain that anger. Results challenged the validity of generalizing easy novice task performance to driving performance.

CHAPTER 1

INTRODUCTION

Talking on one's cell phone negatively affects driving ability. This dual-task interference is an exceptionally robust finding. The Center for Disease Control (2005) reported 43,527 motor vehicle-related fatalities in the United States, and the National Highway Traffic Safety Administration reported that ten percent of individuals driving at any given time of day are using a hands free or handheld cell phone. Evidence that cell phone conversations impair driving performance comes from experimental research as well (e.g., Alm & Nilsson, 1994; Ishida & Matsuura, 2001; McKnight & McKnight, 1993; Strayer & Johnston, 2001). The dangers of concurrent driving and cell phone use are generally accepted as common knowledge. However, the underlying mechanisms of this interference remain a mystery.

Research typically highlights the risks associated with using a cell phone while driving, but rarely acknowledges the benefits (Haigney & Westerman, 2001). The ability to communicate with people in remote locations while driving makes it possible for drivers to conduct business from their cars, thus facilitating a more productive work day (Briem & Hedman, 1995; Faircloth, Ashby, Ross, & Parkes, 1991). This is especially relevant to individuals known as stretch commuters, who travel 50 miles or more to get from home to work. A National Household Travel Survey reported that 3.3 million Americans qualified as stretch commuters in 2004 (Smallen, 2004). Moreover, cell phones provide safety in some situations by enabling drivers to contact emergency services (Redelmeier & Tibshirani, 1997; Stein, Parseghian, & Allen, 1987).

A wide variety of research techniques have been used to study cell phone conversations and driving. Experiments have been conducted in real traffic (e.g., Brown, Tickner, & Simmonds, 1969; Ishida & Matsuura, 2001), in driving simulators (e.g., Alm & Nilsson, 1994; Strayer & Drews, 2007; Strayer, Drews, & Johnston, 2003), and in the laboratory with tasks that represent driving (e.g., Just, Keller, & Cynkar, 2008; Strayer & Johnston, 2001; Wester, Bockner, Volkerts, Verster, & Kenemans, 2008). To measure driving performance in the laboratory, studies have most commonly used pursuit tracking and braking tasks (Horrey & Wickens, 2006). Tasks used to simulate talking on a cell phone include dialing numbers (e.g., Salvucci & Macuga, 2002), mental arithmetic (e.g., McKnight & McKnight, 1993), verb generation (e.g., Strayer & Johnston, 2001), working memory tasks (e.g., Alm & Nilsson, 1995), and realistic conversation with a confederate (e.g., Strayer, et al., 2003). Research has measured physiological reactions with techniques such as functional magnetic resonance imaging (fMRI, e.g., Just, et al., 2008), eye-tracking (e.g., Harbluk, Noy, Trbovich, & Eizenman, 2007), and event related potentials (ERP, e.g., Wester, et al., 2008).

Researchers have conducted several meta-analyses to integrate data collected with this large variety of techniques. Horrey and Wickens (2006) conducted a meta-analysis on 23 studies that investigated the impact of cell phone conversation on driving using five moderating variables: measures of driving performance, handheld vs. hands free phones, conversation vs. information processing tasks, and simulator vs. field studies. They found that conversation affects reaction time (RT) to road events or discrete stimuli more than it affects tracking performance. Effects on driving performance did not statistically differ between handheld and hands free phones. Conversation tasks impacted RT measures of

driving performance more than information processing tasks. However, information processing tasks did produce substantial costs to performance.

Another meta-analysis (Caird, Scialfa, Ho, & Smiley, 2004) examined effects of cell phone use on driving performance by including data from epidemiological and experimental studies. Like Horrey and Wickens (2006), they found no reliable differences in driving performance between handheld and hands free phones. The meta-analysis suggested that, although older adults typically show larger cell phone-related decrements in performance, they are less likely than younger adults to regularly use cell phones while driving. Laboratory studies that used tasks based on driving implied stronger effects of cell phone use on driving performance than on-road and driving simulator studies.

A meta-analysis conducted by Haigney and Westerman (2001) examined some methodological issues in lab-based driving and cell phone studies, such as defining procedures and terms, operationalizing task elements, sampling task components, and using experimental controls. The analysis raised concerns for the ecological validity of tasks used in previous research. For example, there is uncertainty whether the variety of tasks used in studies accurately reflects the variety or balance of cognitive processing required for conversing on a cell phone while driving. Haigney and Westerman concluded that improvements in driving and cell phone research require a more detailed understanding of the underlying mechanisms involved in driving.

Haigney and Westerman's concerns about ecological validity are well exemplified by studies that use simplified perceptual-motor tasks to represent driving. Just et al. (2008) investigated the effects of auditory comprehension on fMRI activity and

performance on simulated driving. Participants performed a lane keeping task while lying in an MRI scanner. They viewed a car moving at a fixed speed down a virtual winding road and controlled the car by moving a mouse or tracking ball with their right hand. Just and colleagues found that a listening task impaired tracking performance, and described this as evidence that listening to someone speak “produces deterioration in driving performance” (pp. 70). Generalizing their results to real driving behavior may be dubious.

In another study that used simple tasks to represent driving, Strayer and Johnston (2001) investigated different types of secondary tasks that might interfere with driving. They used a pursuit tracking task to represent driving, in which participants used a mouse to keep a cursor aligned with a circular object moving in sine wave patterns across a computer screen. In one of the two experiments, they included a braking task, in which participants pressed a button in response to the moving object occasionally turning red. They found that easy secondary tasks (i.e., shadowing speech, listening to radio broadcasts) did not impair tracking or braking performance, whereas harder secondary tasks (i.e., an information-generating verbal task, conversation with a confederate) did impair performance. They interpreted these results as evidence that talking on one’s cell phone interferes with driving by diverting attention to an engaging context unrelated to driving.

Concerned with the ecological validity of their findings, Strayer and colleagues (Strayer, et al., 2003) conducted a similar experiment using a high fidelity driving simulator. Participants engaged in a car-following task while different dependent variables (e.g., break onset time, following distance) were recorded. Participants

conversed with a confederate as a secondary task, but the other secondary tasks from the 2001 study were not used. Results showed that the conversation interfered with all of the driving dependent variables. The researchers described the study as a successful replication and extension of their findings from Strayer and Johnston (2001).

1.1 Explanations for Interference

Existing theories for the mechanisms of interference associated with driving and cell phone use are vague. One popular theory proposes that interference is caused by a kind of inattention blindness, which occurs when an individual fails to observe salient stimuli and distinct objects to which they have perceptual access (Simons, 2000). This Inattention Blindness hypothesis attributes the costs of cell phone use on driving to diverting attention away from driving to the conversation. Whereas this hypothesis focuses on the perceptual consequences of interference, other more established models focus more on the underlying structure of attention.

Numerous explanations of the architecture of attention have been developed. Resource models are among the most well known hypotheses (c.f., Pashler, 1998). These models assume that there is a limited resource or resources that can be allocated to multiple tasks. Unitary Resource theories (Kahneman, 1973; McCleod, 1977) assume that multiple task performance is arbitrated by a single, amodal mental commodity that can be quantified, divided, and allocated (Wickens, 1991). Conversely, Multiple Resource theories assume that different tasks require different modality-specific sets of resources. Therefore, if two tasks demand separate resources (i.e., different input and output modalities), they may be performed concurrently with no interference (Navon & Gopher, 1979).

Between these two classes of theories, Unitary Resource models better account for the evidence that talking on a cell phone (handheld or hands free) interferes with driving performance. Talking on one's cell phone impairs driving ability, even though the tasks involve different modalities. Reduced to their most basic components, driving requires manual responses to visual stimuli, whereas conversation requires vocal responses to auditory stimuli. The inability to simultaneously perform these tasks well implicates an amodal source of attention.

The Central Capacity Sharing model (Tombu & Jolicoeur, 2003) is a prominent, more specific type of unitary resource model. It assumes that some processing stages are not capacity-limited and that other stages are. Specifically, central processing stages (i.e., response selection) are capacity-limited. Central resources must be shared among multiple competing tasks. When this processing capacity is shared, multiple tasks are processed more slowly than they would be individually. Because driving is a continuous activity, a prediction follows that a telephone conversation (which is also more or less continuous) will repeatedly overlap with driving at central processing stages.

The model posits that while the capacity of central processing is limited, it may not be fixed. Rather, it may increase when more effort is expended on the tasks to be performed (Kahneman, 1973). It is reasonable to think that after countless hours spent driving, an individual may put less effort into their driving performance and therefore, have less processing capacity. This could be problematic in the event of a sudden and unexpected obstacle such as a squirrel running into the street.

Although resource models provide explanations for dual-task interference in driving, they cannot necessarily quantify the stages of processing. Haigney and

Westerman (2001) proposed that improvements to research demand a better understanding of the underlying mechanisms of driving. Computational models of cognition can provide a more detailed and mechanistic account of driving.

1.2 Computational Models of Dual-task Interference

Human performance has often been studied with computational models of humans performing various tasks. One such architecture, Executive-Process/Interactive Control (EPIC), characterizes human performance of simultaneous perceptual-motor and cognitive processes (Meyer & Kieras, 1997a, 1997b, 1999; Meyer, et al., 1995). Performance of various tasks is accomplished through a series of processing stages (i.e., stimulus encoding, response selection, and response execution) similar to discrete stage models (Sanders, 1980; Sternberg, 1969).

EPIC's principle components, which facilitate the processing stages, include distinct processing units (e.g., visual processor, auditory processor) that receive inputs from simulated physical effectors based on human physiology. These perceptual processors output information to a working memory store, which is controlled by a cognitive processor to perform various actions. The cognitive processor analyzes the inputs from the perceptual processors, selects appropriate responses, and sends them to motor processors, which prepare and execute movement through the physical effectors. In a dual-task situation, any of the processing stages (stimulus encoding, response selection, response execution) can operate in parallel.

From the EPIC architecture, Meyer and Kieras formulated a class of Adaptive Executive Control (AEC) models that use executive processes to control the course of secondary task processing stages. According to these models, skills for performing

individual tasks are acquired by transforming declarative knowledge into procedural knowledge (Anderson, 1982; Bovair & Kieras, 1991). After sufficient practice has converted knowledge from declarative to procedural, EPIC's cognitive processor can process and execute two tasks simultaneously if those two tasks use different sensory processing units.

AEC models predict that perfect time sharing between two well-practiced tasks is possible when stimuli and responses use different modalities (Meyer & Kieras, 1997a, 1997b; Schumacher, et al., 2001). Schumacher and colleagues tested this prediction by pairing an auditory-visual (AV) choice reaction task with a visual-manual (VM) choice reaction task. A dual-task trial entailed an auditory stimulus and a visual stimulus appearing concurrently, and participants were instructed to give equal priority to both tasks. After 5 or 6 sessions of practice, many of the participants achieved perfect time sharing. That is, they responded as quickly and accurately to the dual-task trials as the single-task trials. A series of experiments by Ruthruff, Hazeltine, and colleagues have also demonstrated that some individuals can be trained to simultaneously perform two tasks with different modality pairings without interference (Hazeltine & Ruthruff, 2006; Hazeltine, Ruthruff, & Remington, 2006; Hazeltine, Teague, & Ivry, 2002; Ruthruff, Hazeltine, & Remington, 2006; Ruthruff, Johnston, Van Selst, Whitsell, & Remington, 2003).

Driving a car and talking on a cell phone also require different modality pairings. A conversation requires attending to auditory inputs and producing vocal outputs, whereas driving primarily requires attending to visual inputs and producing manual outputs. For experienced drivers, the declarative knowledge demanded by these skills has

most likely been converted to procedural knowledge. Thus AEC models might predict that it is possible for these tasks to be performed simultaneously without interference.

Adaptive Character of Thought (ACT-R) is another computational cognitive architecture. Like EPIC, it hypothesizes that complex cognition is mediated by an interaction between declarative and procedural knowledge (Anderson, 1993, 1996; Lebiere & Anderson, 1998). A variant of this architecture, ACT-R/PM (Perceptual-Motor), integrates the ACT-R production system with a set of perceptual-motor modules inspired by EPIC (Byrne & Anderson, 2001). ACT-R/PM's principle components include perceptual-motor modules for vision, movement, speech, and audition that communicate with a cognitive layer of declarative and production memory in which central cognition (viz., response selection) occurs. Central cognition and the perceptual-motor modules run parallel with each other, but, unlike EPIC, response selection in the cognitive layer is serial.

ACT-R/PM predicts that different modality pairings and cognitively simple tasks can facilitate performance that resembles perfect time sharing. However, the serial cognitive layer of the architecture does not allow for actual parallel central processing (Byrne & Anderson, 2001). Instead, the model predicts that two easy tasks can be performed without interference when the central processing stages for the two tasks do not overlap. For example, if stimuli for an AV task and a VM task were presented simultaneously, encoding of the auditory stimulus could overlap with response selection for the VM task. Similarly, response selection for the AV task could overlap with the response execution stage of the VM task. Thus if response selection for one task is complete before response selection for the other task begins, performance would

resemble perfect time sharing. ACT-R/PM predicts that a perfect time sharing event is likely to occur only when the tasks demand minimal central processing. Therefore, this model might predict that more cognitively complex tasks like driving and conversation would entail overlapping central processing.

1.3 Limitations of cell phone & driving research

The interactions and mechanisms of cell phone use and driving are intrinsically difficult to study. Both behaviors are multifaceted and require cognitive and physiological demand characteristics that differ along numerous parameters. Task analysis of driving behavior further illustrates the complexities of driving. Fastermeier and Gstalter (2007) developed a framework for task analysis based on classifications of road traffic situations and a model of a driver's information processing. The classifications of traffic situations yielded three main elements: road design, road layout, and traffic flow. Within these elements, they identified 16 categories of road type (e.g., two-lane rural road), 9 categories of road layout (e.g., signalized junction with traffic lights), and 6 categories of traffic flow (e.g., right turn).

Fastermeier and Gstalter's model of driver information processing produced an even more elaborate structure of elements and categories than the classifications of traffic situations. Basic driving behavior was divided into a navigational level and a control level. The control level included steering, speed control, supervision of car conditions (e.g., the speedometer), self assessment of driver state (e.g., fatigue), and control of selective attention. The category of control of selective attention included subcategories such as observing oncoming traffic and following traffic rules.

The variety of situations and subtasks possible for a cell phone conversation are arguably no simpler than those possible for driving. As with driving, different types of demand characteristics required are dependent on the situation. At a basic level, finding a number in a phone may involve perceptual and visual processing, whereas participating in a conversation may involve a combination of auditory, visual, and central processing. Such simple assumptions cannot be made for the content of conversations. The different types of demand characteristics could be affected by anything from the presence or absence of emotional content to the quality of the connection between the two phones (Haigney & Westerman, 2001). For example, an individual might be describing directions to a certain place. The difficulty of this task might depend on spatial processing, which is susceptible to individual differences (Hunt, 1978). These differences in the cognitive and physiological processing requirements of the two tasks are frequently ignored in research. Existing studies tend to adopt an assumption that characteristics of the driving task are constant and concentrate only on a small range of cell phone operations (Haigney & Westerman, 2001).

Along with the complexities of driving and conversation, learning and practice effects are frequently ignored in cell phone and driving research. (Shinar, Tractinsky, & Compton, 2005). As an individual learns to drive, much of their improvement is based on the subtle and slowly developing improvements in the quality of information acquisition and processing (Mourant & Rockwell, 1972; Shinar, Meir, & Ben-Shoham, 1998). Practice is also emphasized in computational human processing models. In the EPIC architecture, practice is essential in transforming declarative knowledge to procedural

knowledge and thus facilitating skilled performance (Meyer & Kieras, 1997a, 1997b, 1999; Meyer, et al., 1995).

According to some influential attention investigators (e.g., Posner & Snyder, 1975; Schneider & Shiffrin, 1977), mental operations that are extensively practiced go through qualitative changes. Through practice, control processes are functionally reorganized from slow and capacity-limited to fast and automatic (Logan, 1988). On the other hand, some attention researchers (Newell & Rosenbloom, 1980) propose that rather than qualitative changes, practice facilitates quantitative changes in processing. Through practice, control processes become more efficient but do not undergo reorganization. Imaging research suggests that practice leads to both types of changes in processing (Schumacher, Hendricks, & D'Esposito, 2005). Both ideas present serious challenges to many one-session driving studies that use simple perceptual-motor tasks to represent driving (e.g., Just, et al., 2008; Strayer & Johnston, 2001). If an easy but unpracticed task (e.g., pursuit tracking) and a more complex but well practiced task (i.e., driving) involve control processes that differ in organization and efficiency, it may be inappropriate to generalize performance on one task to the other.

Despite the importance of practice in driving, most cell phone and driving studies consist only of one session (Shinar, et al., 2005). This includes even the most well-known studies that have influenced legislation and subsequent research (e.g., Brown, et al., 1969; McKnight & McKnight, 1993; Strayer & Johnston, 2001). Although these studies remain influential, the limitations caused by lack of practice has been discussed in meta-analyses (e.g., McCartt, Hellinga, & Bratiman, 2006). It has also been reported that laboratory studies that use tasks representative of driving show much more dual-task interference

than on-road and simulator studies (Caird, et al., 2004). It is possible that on-road and simulator studies show less interference, in part, because the participants in these studies are already practiced with the driving tasks.

In one study that did investigate the role of practice, Shinar, Tractinsky, and Compton (2005) gave participants five sessions to practice the driving and conversation tasks. To represent conversation, participants either performed math operations or conversed with a remote confederate. Interference with driving performance in these dual-task conditions was initially high, but decreased significantly over the five sessions. However, 5th session data did show impaired driving performance in the dual-task conditions. The results suggest that although there may be risks associated with cell phone use while driving, research has likely overestimated these risks.

Practice is only one of many important components that are frequently ignored in research. Other variables include lack of emotional content in conversation, dissimilarities between experimental driving tasks and real driving behavior, and speed accuracy tradeoffs (Dressel & Atchley, 2008). These numerous issues have made it difficult to create research procedures that accurately quantify dual-task interference in a cell phone and driving context (Haigney & Westerman, 2001).

1.4 Mechanisms of Interference

Efficiently controlling a vehicle is a cognitively complex process that involves extracting and integrating information from multiple sources (Harbluk, Noy, & Eizenman, 2002). The majority of legislation regulating cell phone use assumes that impairments in driving are caused by peripheral factors like holding a phone to one's ear. It is illegal in five states to drive while talking on a handheld cell phone, but there are no

bans in the United States against hands free cell phones (Govenors Highway Safety Administration, 2008). However, as mentioned previously, meta-analyses suggest that hands free cell phones are no safer than their handheld counterparts (Caird, et al., 2004; Horrey & Wickens, 2006), implying that central, instead of – or in addition to – peripheral, processes are the locus of interference.

Most driving and cell phone research implicates central cognition as the key locus of interference; however, it is still unclear whether tasks that require attention (but not necessarily response selection) interfere with driving performance. Some research suggests that tasks like attending to verbal information and shadowing speech interfere with driving performance; some research suggests that they do not. For example, Pizzighello and Bressan (2008) conducted a study in which they instructed observers to watch a visual display while simultaneously listening to short stories or lists of words. During the experiment, an unexpected visual object appeared on the display. Results showed that attending to either of the verbal streams reduced the probability of detecting the appearance of the visual object.

Recarte and Nunes (2003) also demonstrated that a task without response selection can potentially interfere with driving. Participants drove while performing one of two secondary tasks: one task required vocal responses and the other required listening only. They found that both secondary tasks impaired spatial gaze concentration and visual-detection. However, the listening task created significantly less interference than the vocal response task.

Other studies suggest that easy attentional tasks do not interfere with driving performance. For example, McCarley and colleagues (2004) investigated change

detection while driving in dual-task scenarios. Participants conversing on a hands free cell phone showed impaired performance in detecting changes in traffic scenes. However, listening to prerecorded conversations from other participants did not interfere with change detection performance.

Strayer and Johnston (2001) found that engaging in conversation interfered with performance on pursuit tracking and braking tasks, but listening to radio broadcasts did not. Moreover, a task requiring listening and speech production (mentioned earlier) produced no observable interference. In this task, an experimenter read a word to the participant every 10 to 20 seconds, and the participant repeated that word. There were no reliable differences between driving performance in this condition and in the single-task driving condition. This study suggests that listening to auditory inputs and producing vocal outputs, by themselves, do not demand enough attention to disrupt driving performance. Instead, it appears that attending to visual inputs is disrupted by the central processing involved in conversation (Strayer, et al., 2003). However, as discussed earlier in this section, some studies have found evidence that tasks requiring little or no central processing can interfere with driving (e.g., Pizzighello & Bressan, 2008; Recarte & Nunes, 2003).

1.5 Emotion Regulation

The failure to consider emotion's impact on performance is a common criticism of cell phone and driving research (Haigney & Westerman, 2001; McCartt, et al., 2006). Survey research suggests that up to 65% of naturally occurring conversations from vehicles involve intense verbal negotiation (McCartt, et al., 2006). Experimental studies often attempt to simulate conversation with verbal transformation and number-based

tasks (e.g., Boase, 1988; Brown, et al., 1969; Faircloth, et al., 1991). These tasks, meant to represent conversation, have been criticized as lacking ecological validity (e.g., Brookhuis, Devries, & Dewaard, 1991; Shinar, et al., 2005).

Cell phone conversations are capable of changing a driver's emotional state (e.g., angry, happy, sad), which may also affect driving performance. Within the literature on emotion's effects on performance, there is extensive evidence that heightened emotion, by itself, does not reliably interfere with performance in perceptual-motor and information processing tasks. However, attempts to down-regulate or stifle emotion have been repeatedly shown to impair task performance (e.g., Richards & Gross, 2000; Scheibe & Blanchard-Fields, 2009).

Emotion regulation is composed of external and internal processes that monitor, assess, and alter emotional reactions to achieve one's goal (Thompson, 1994). Emotion regulation is believed to operate on multiple levels of cognition. The cognitive processes used in emotion regulation may be controlled or automatic, conscious or unconscious, and located at different stages in the process of generating emotions (Green & Malhi, 2006). Research on emotion regulation investigates how and to what extent people can control which emotions they experience, when they experience them, and how they express them (Gross, 1998).

There has been controversy over whether emotion regulation is a necessary adaptive strategy or a dangerous habit (Gross & Levenson, 1997). Most medical research supports the latter account (Hosie, Milne, & McArthur, 2005). For example, continuously suppressing anger has been linked to increased risk for coronary heart disease, hypertension, and less severe problems such as recurring headaches (Gallacher, Yarnell,

Sweetnam, Elwood, & Stansfeld, 1999; Venable, Carlson, & Wilson, 2001). More recently, psychological research has established the value of emotion regulation (Hosie, et al., 2005). For example, constantly expressing feelings of anger can lead to detrimental social consequences such as marriage and family problems, destruction to property, and decreased levels of efficiency in the workplace (Deffenbacher, Oetting, Lynch, & Morris, 1996). However, it should be noted that the consequences of emotion regulation processes depend heavily upon the specific strategies used (Gross, 2002).

Regardless of whether the benefits of regulating one's emotions outweigh the costs, extensive research has found emotion regulation to be cognitively taxing, impairing performance in working memory and other information processing tasks (Baumeister, Vohs, & Tice, 2007; Richards, 2004; Scheibe & Blanchard-Fields, 2009). For example, Baumeister, Bratslavsky, Muraven, and Tice (1998) demonstrated that emotion regulation negatively affects performance on information processing tasks. Participants watched an emotionally evocative film and were given one of two instructions. Half were told to not show or feel any emotion, and half were told to "let their emotions flow" during the movie. After the movie, participants were given anagrams to solve. The groups instructed to feel the emotions elicited by the film solved the anagrams with nearly twice as much success as the group told not to show or feel emotions.

Scheibe & Blanchard-Fields (2009) investigated the effects of emotion regulation on young and older adults. After practicing a working memory task, participants watched a short film clip that has been shown to induce disgust (Shiota & Levenson, 2008). They were given instructions to either down-regulate any negative emotions or to maintain any negative emotions. There was also a group that was not given emotion regulatory

instructions and a group that watched a neutral film clip. After watching the film clip, participants performed the same working memory task as earlier in the experiment. In the emotion down-regulation group, young adults showed decrements in performing the task, whereas older adults showed improved performance. Performance on the working memory task was not affected by instructions to maintain negative emotions. Results suggest that efficient emotion regulation is a skill mastered only later in life.

1.6 Ego Depletion Model

The Ego Depletion model attempts to explain the negative effects of emotion regulation on performance and memory (Baumeister, Bratslavsky, et al., 1998). The model centers around the idea that an individual's acts of volition (i.e., choosing and making decisions, assuming responsibility, inhibiting behavior, planning actions and executing those plans) draw on a limited resource, similar to strength or energy. Thus an act of volition will detrimentally impact subsequent acts (Baumeister, Bratslavsky, et al., 1998). Self-regulation, for example, entails withstanding temptation and therefore overrides motivated behaviors. Exerting the control needed for this act draws on this limited reserve of strength and may quickly exhaust it (Muraven, Tice, & Baumeister, 1998).

A major element of the Ego Depletion model is the hypothesis that the strength required in a variety of the self's operations is taken from a single source. That is, the same resource is used in self-regulatory functions, including emotion regulation and performance regulation. Another hypothesis of this model is that this source of strength or energy is limited (Baumeister, Muraven, & Tice, 2000). Together, these hypotheses

imply that an individual's ability to down-regulate an emotion will directly compete with that individual's ability to perform information processing and perceptual-motor tasks.

The Ego Depletion model bears a strong resemblance to Kahneman's Unitary Resource theory (1973), which many researchers have provided evidence against (e.g., Wickens, 1980). Moreover, there is ample behavioral and computational evidence that attention is, to some extent, modality-specific (Meyer & Kieras, 1997a, 1997b; Schumacher, et al., 2001). Perhaps this conflict can be resolved with an idea that there are multiple layers of cognitive processing. For example, basic perceptual-motor tasks may involve a modality-specific simple cognitive layer, and more complicated information generating tasks may involve an amodal complex cognitive layer. This would accommodate evidence for the Ego Depletion model's unitary source of energy (e.g., Baumeister, Dale, & Tice, 1998; Baumeister & Heatherton, 1996; Baumeister, Heatherton, & Tice, 1994) and evidence for models like EPIC that assume modality-specific processors (Meyer & Kieras, 1997a, 1997b; Schumacher, et al., 2001).

1.7 Current Experiment

Regardless of cognitive structure, almost all research on cell phone use and driving suggests that performing both of these tasks at the same time presents statistically significant safety risks. Among the many multiple-task theories and architectures, there are some (e.g., Capacity Sharing) that account for the literature better than others (e.g., Multiple Resource). Studies on this topic frequently ignore vital aspects of real world behavior such as practice effects in driving and emotional content in the conversation. Perhaps these and other flaws in the research are why the specific underlying mechanisms of interference of cell phone use on driving remain unknown. The current

experiment addresses these problems by investigating three critical features as they apply to concurrent cell phone use and driving: the practice effects of driving tasks in the laboratory, the underlying mechanisms of interference of multi-task performance, and the effects of emotion and emotion regulation on driving performance.

In the current study, participants performed a driving task under various conditions. All participants completed a practice session and six additional sessions. Similar to Strayer and Johnston (2001), a pursuit tracking task represented driving, and two verbal tasks served as secondary (cell phone) tasks. One verbal task required listening and speaking but little semantic processing, and the other task involved vocally generating semantic information in response to auditory stimuli. During the final session, an emotion, anger, was induced. Half of the participants were instructed to down-regulate any negative emotions, and the other half were instructed to maintain any negative emotions. This allowed investigation of the mechanisms of dual-task interference, and the effects of practice, emotion, and emotion regulation on tasks to represent driving and talking on a cell phone.

CHAPTER 2

METHOD

2.1 Participants

Fifteen participants (8 males, 7 females; ages 19 – 28, mean = 21.7) from the Georgia Institute of Technology participated in this study. The participants had normal or corrected to normal vision and hearing. Participants were required to have had a valid driver's license for at least two years and to speak English as a first language. They received \$70 or \$77 (based on performance) for approximately 7 hours of participation.

2.2 Stimuli and Apparatus

Volunteers participated in seven sessions sitting approximately 72 cm from two computer monitors in a quiet, semi-dark room. They performed a pursuit tracking task on an IBM laptop in which they used a Logitech optical mouse to keep a cursor aligned with a moving target. They performed a verbal task on an IBM desktop. Dell speakers presented the verbal task stimuli, and an Audio Technica microphone recorded vocal responses. The tasks were programmed using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002). In the final session, participants watched a short film clip from the film *Cry Freedom* (Briley & Woods, 1987). The clip depicts soldiers in South Africa attacking a group of civilians who had been peacefully protesting racial discrimination laws.

2.3 Tasks and Design

The primary tracking task replicates the task from Experiment 2 of Strayer and Johnston (2001). Participants controlled a mouse with their right hand to keep a black

cross-shaped cursor on a white computer screen aligned as closely as possible with a circular moving target. The screen's refresh rate was 33 ms, and the target's course was determined by the sum of three randomly generated sine waves. Target movement was unpredictable, yet smooth and continuous.

Participants also performed two types of secondary verbal tasks throughout the experiment: a paired associate (PA) task and a verb generation (VG) task. The PA task required participants to respond to a spoken noun with a previously memorized, semantically unrelated verb. Natural Reader 7, software that transforms text into speech, generated sound files of the spoken words. There were a total of eight word pairs, and all 16 nouns and verbs consisted of one syllable. The list of paired associates was the same for all participants throughout all sessions. The nouns in half of the word pairs pertained to the clip from *Cry Freedom* (i.e., child, dirt, road, wound), whereas half were unrelated (i.e., lamb, pear, seed, vest)¹.

The VG task required participants to vocalize a verb related to a spoken noun presented through Natural Reader 7 software. The stimuli consisted of over 1000 nouns taken from the MRC Psycholinguistics database (Wilson, 1988). A total of 700 words were used. The criteria for the selected words included concreteness and familiarity ratings between 400 and 700 (ratings for these categories range from 100 to 700). All words consisted of three or fewer syllables and 4-8 letters. Each word was presented only

¹There were two primary reasons for using words semantically related to the film in the verbal tasks. First, the anger incited by the film was meant to persist throughout the session, and it is difficult to determine the duration of emotions elicited by films. By using content related to the film for the verbal tasks, participants were more likely to remember the film, and thus more likely to maintain their anger. Second, the semantic relationships made the verbal tasks more representative of an actual argument. When individuals argue, the content of their conversations typically relates to the source of conflict.

once (480 words) or twice (220 words) for individual participants throughout the 7 sessions. Words never repeated themselves in the same session. Words were distributed evenly across the sessions based on concreteness, familiarity, number of syllables, and letter count. Thirty-one percent of the VG nouns used in session 7 were related to the film clip (e.g., soldier, blood).

During session 7, participants were shown a film clip intended to make them angry. The film clip has been shown to reliably induce anger in male and female participants of various ethnic backgrounds (Gross & Levenson, 1995; Hewig, et al., 2005; Philippot, 1993). Windows Media Player played the film clip (Briley & Woods, 1987) on the laptop computer, while the desktop showed a blank screen.

There were two experimental groups in this experiment: *emotion down-regulation* and *maintenance control*. After watching the film clip during the final session, participants in the emotion down-regulation group were told,

The movie you just saw probably caused you to experience a negative emotional reaction. When working on the next tasks, we would like you to down-regulate that negative emotion as fast as you can. At the same time, remember it is important that you do a good job in performing the other tasks.

Participants in the maintenance control group were told,

The movie you just saw probably caused you to experience a negative emotional reaction. When working on the next tasks, we would like you to maintain the intensity of your negative reaction to the film. Just keep your negative feelings going and do not try to change them in any way. At the same time, remember it is important that you do a good job in performing the other tasks.

Throughout the experiment, participants completed emotion self report inventories similar to those used in Scheibe and Blanchard-Fields (2009). Participants

reported the extent to which they felt each of eight emotions on a 5-point scale, from 1 (*very slightly*) to 5 (*extremely*). The emotions (anger, anxiety, contentment, disgust, frustration, happiness, interest, and sadness) were presented in a random order each time the inventory was administered. For the first 6 sessions, the self report inventories were used to check for strong negative emotions that could potentially influence performance. In session 7, the inventories were used to measure the initial effects of the film on the participants, and whether they were following their emotion down-regulation or maintenance control instructions.

2.4 Procedure

Each participant completed the seven sessions within three weeks and completed session 7 no more than a day after session 6. In session 1, the participants read and signed a consent form and completed an abbreviated version of the Unsafe Driving Behaviors Questionnaire (Administration, 1998). The participants learned and practiced the three tasks (tracking, PA, VG) individually. These single-task blocks amounted to 8 minutes of tracking (over 2 blocks), 89 trials of the PA task (over 4 blocks), and 67 trials of the VG task (over 3 blocks). The order in which participants learned the tasks was counterbalanced. At the end of the session, participants practiced two dual-task blocks for four minutes each.

Throughout the experiment, the tracking and verbal tasks, as well as the combinations of those tasks, resulted in 5 different block types. Three of these were single-task blocks: *tracking*, *PA*, and *VG*. The two dual-task blocks consisted of simultaneous tracking and PA tasks (*tracking-PA*) and simultaneous tracking and VG tasks (*tracking-VG*). The single-task tracking and dual-task blocks lasted for 4 minutes, and the

single-task verbal blocks lasted for 2 minutes. In all but the single-task tracking block, E-Prime 2.0 presented the spoken words at randomized intervals of 4, 6, 8, and 10 seconds. Dual-task verbal blocks included 34 verbal task trials, and single-task verbal blocks included 17 trials.

In sessions 2 through 6, participants completed a brief warm-up of shortened dual- and single-task blocks. The single-task blocks consisted of 1 minute of tracking, 10 trials of the PA task and 10 trials of the VG task. Dual-task practice blocks included a 2 minute tracking-PA block and a 2 minute tracking-VG block. After the warm-up, participants performed two cycles of the 5 block types. The order of the blocks was counterbalanced across participants, but the order remained constant within each participant. After session 6, participants were placed into the emotion down-regulation group or the maintenance control group based on their tracking performance over sessions 2 through 6, with a focus on session 6 (as this session acted as a control for session 7). Group placement was delayed until this time to ensure that both groups began session 7 with similar levels of performance, and to make the experiment double-blind for as long as possible.

Session 7 began with a self report inventory and a warm-up, as in the other sessions. The experimenter then said,

You may find some of the events depicted in this clip upsetting. Nevertheless it is important that you watch the film as carefully as possible. You may look away if you find any images too distressing and if you find the film too upsetting, feel free to leave the room.

The experimenter left the room while the participant watched the film clip from Cry Freedom. After the film, the participant completed a self report inventory to determine the initial effects of the film. The experimenter then instructed participants to either down-regulate or maintain any negative emotions experienced during the film.

The participant then continued to perform the two cycles of the block types. Between blocks, participants completed additional self report inventories to monitor their success in following their instructions. Immediately before each block, a screen with images from the film clip and a written reminder of their emotion instructions appeared for 5 seconds.

After the tracking and verbal blocks, participants rated the 8 nouns and 8 verbs used in the PA task and all of the nouns used in the VG task during session 7 in terms of how much they related to the film clip. Relatedness was rated on a 5-point scale from 1 (*not at all*) to 5 (*extremely*). Participants were then debriefed and compensated.

CHAPTER 3

RESULTS

3.1 Outlier Removal

Root mean squared error (RMSE) of the cursor from the target provided a measure of tracking performance. Outlier removal began with dividing the 4 minute blocks into 14 sections (the number of times the target moved across the screen in a block). The mean RMSE was calculated within each block, and sections were removed if their average was greater than three standard deviations above the mean of that block. This procedure excluded 1.5% of the tracking data from analysis. Reaction times and accuracies of the paired associate and verb generation tasks assessed verbal task performance. Incorrect trials and trials with an RT over 3000ms were excluded from the analysis. This procedure excluded 1.2% of PA trials and 3.8% of VG trials.

3.2 Tracking

Three of the 15 participants failed to perform the primary task adequately, and their data were excluded from the analyses. A repeated measures ANOVA of tracking RMSE data collected during sessions 2 through 6 showed a statistically significant main effect of session, $F(4,44) = 3.474$, $p = .015$ (see Figure 1). The analysis also revealed a reliable main effect of secondary task on tracking performance, $F(2,22) = 4.486$, $p = .041$. A Hynh-Feldt correction was used for this p -value, because the secondary task

variable violated the sphericity assumption². Planned comparisons showed that performing either of the verbal tasks interfered reliably with tracking performance. The interaction between session and secondary task approached significance, $F(8,88) = 1.816$, $p = .085$.

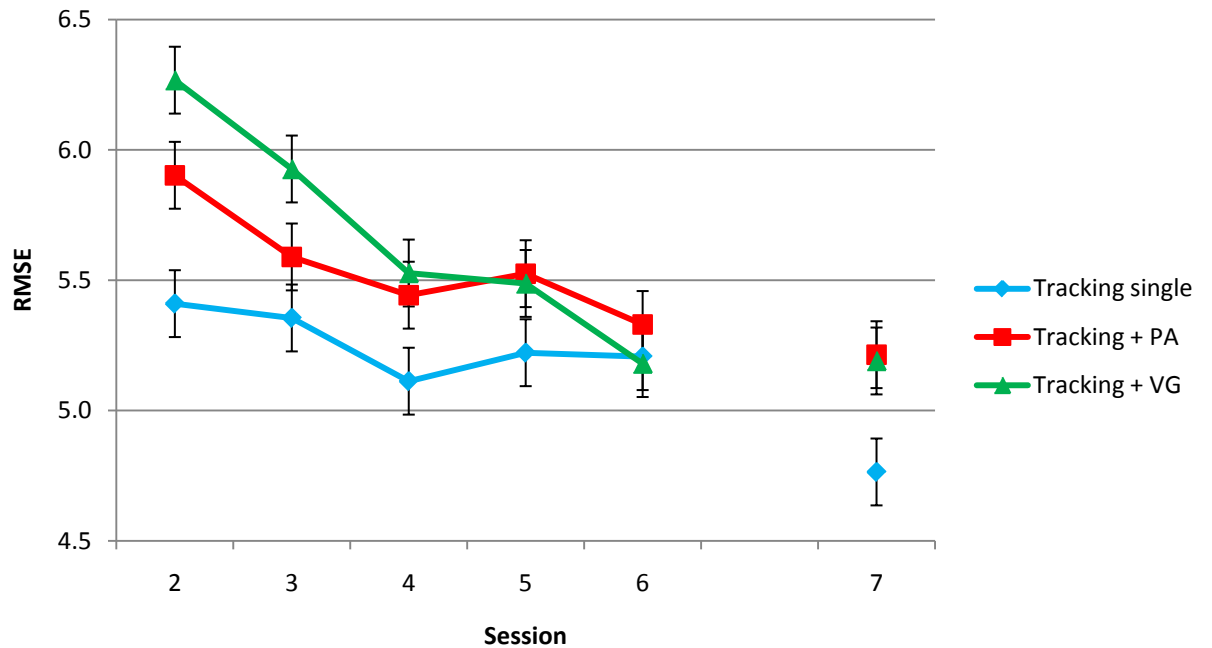


Figure 1: Tracking Data for Session 2 through Session 7.
Root mean square error for the tracking task across sessions.

Within session 2, there was a reliable main effect of secondary task, $F(2,22) = 8.734$, $p = .002$. Planned comparisons showed that tracking performance was impaired by a secondary PA task, $F(1,11) = 9.621$, $p = .010$, and a secondary VG task $F(1,11) = 13.053$, $p = .004$. The difference in tracking performance between PA and VG blocks was

² Data did not violate the sphericity assumption unless otherwise noted.

not reliable. Within session 3, there was also a main effect of secondary task, $F(2,22) = 3.566, p = .046$, but planned comparisons revealed that tracking performance was impaired by the VG task only, $F(1,11) = 6.216, p = .030$. Thus the PA task did not reliably interfere with the tracking task by session 3. Within sessions 4, 5, and 6, tracking data were not affected by the secondary task.

The interaction between session and secondary task was investigated further by investigating the first (session 2) and last (session 6) sessions only. These data are less likely to be affected by participant differences in learning and performance across the intermediate sessions. A repeated measures ANOVA of tracking data from session 2 and session 6 showed main effects of session, $F(1,11) = 7.392, p = .020$, and secondary task, $F(2,22) = 3.584, p = .045$, as well as an interaction between session and secondary task, $F(2,22) = 5.004, p = .016$.

3.3 Paired Associate

A repeated measures ANOVA on RT data for the PA task during sessions 2 through 6 showed a significant main effect of session, $F(4,40) = 13.166, p < .001$ (see Figure 2). RT was slower when the participant was concurrently performing the tracking task (dual-task) than when performing the PA task alone (single-task), $F(1,10) = 5.854, p = .036$. Session did not interact reliably with task type (single-task, dual-task).

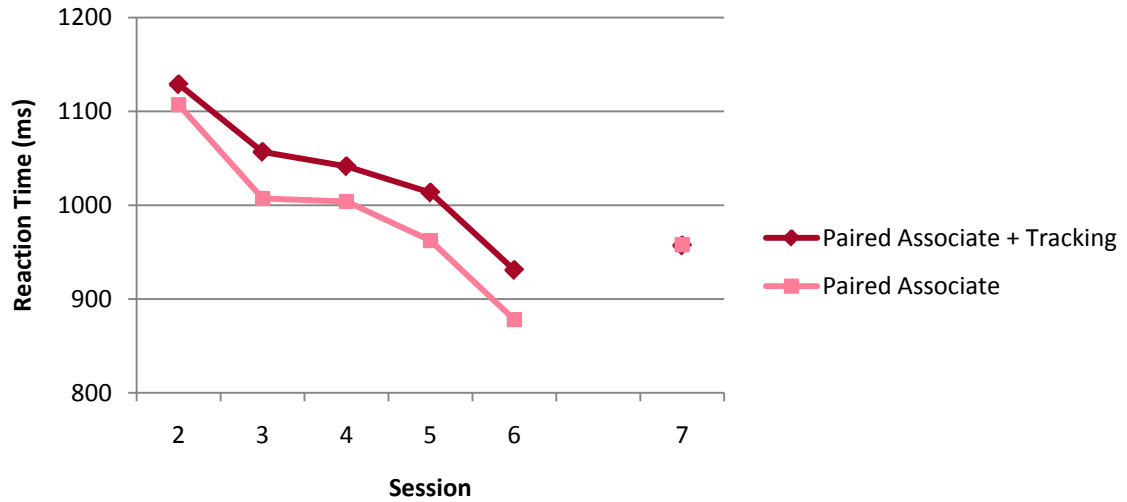


Figure 2: Paired Associate Reaction Time Data for Session 2 through Session 7.
Mean reaction times for the paired associate task across sessions.

Like the tracking data, the PA data from only session 2 and session 6 were analyzed. A statistically significant main effect of session emerged, $F(1,10) = 51.858, p < .001$, but there was no reliable effect of task type on PA performance. An arcsine transformation was applied to the error rates from sessions 2 and 6 to stabilize the variance (Kleinbaum, Kupper, Muller, & Nizam, 1998), and the transformed data were analyzed with a repeated measures ANOVA. This analysis showed that participants were less accurate in dual-task blocks than single-task blocks, $F(1,10) = 8.412, p = .016$ (see Figure 3).

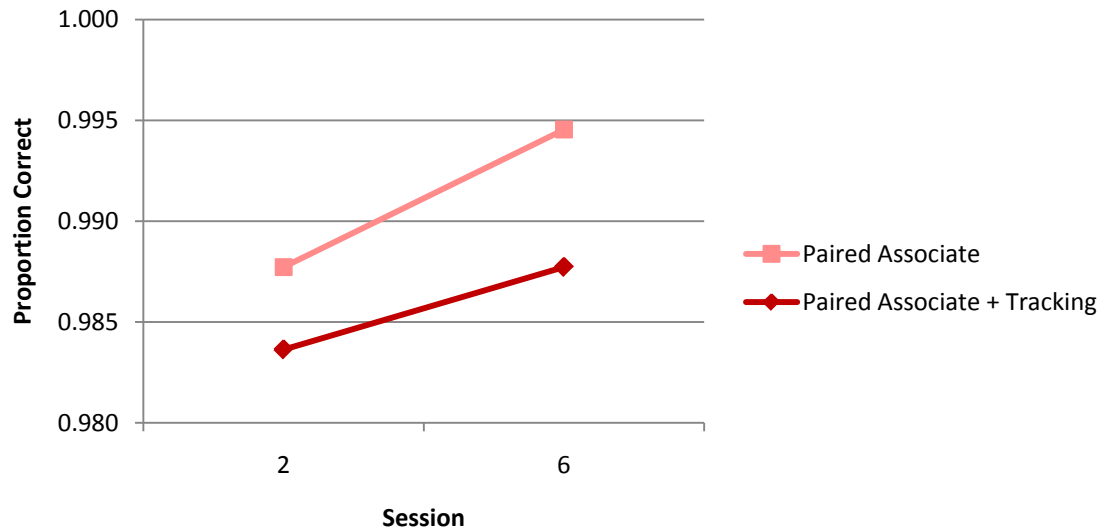


Figure 3: Paired Associate Accuracy Data for Session 2 and Session 6.
Percentage of correctly answered paired associate trials.

3.4 Verb Generation

A repeated measures ANOVA on RT data for the VG task during sessions 2 through 6 revealed a statistically significant main effect of session, $F(4,40) = 3.269$, $p = .021$, but no reliable effect of task type (see Figure 4). However, session and task type reliably interacted with each other, $F(4,40) = 5.559$, $p < .001$. Before extensive practice, participants responded more quickly to the VG task while concurrently performing the tracking task than while performing the VG task alone. By session 6, participants responded more slowly during dual-task blocks than single-task blocks.

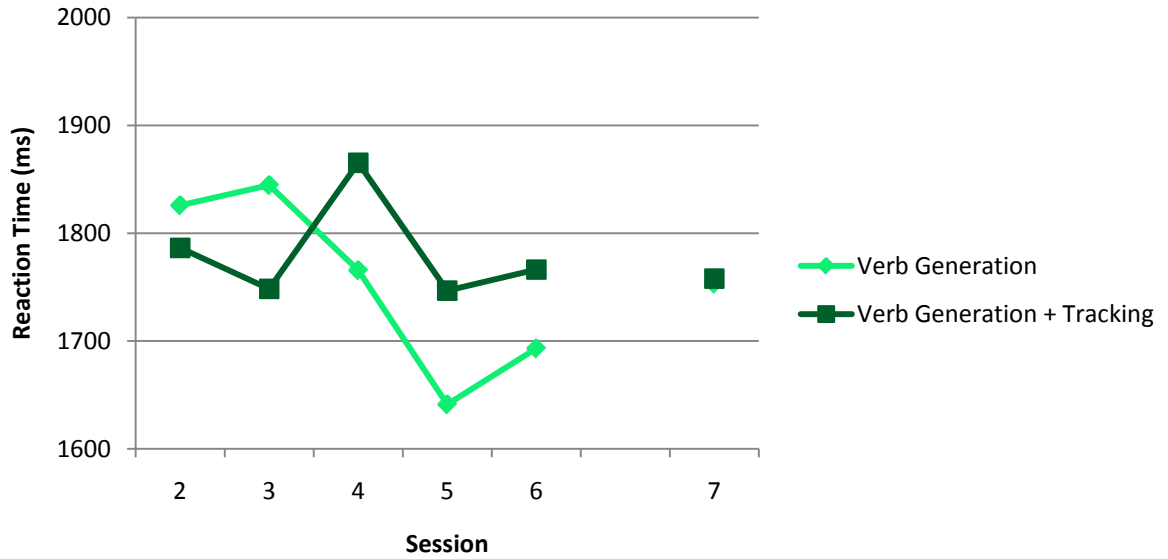


Figure 4: Verb Generation Reaction Time Data for Session 2 through Session 7. Mean reaction times for the verb generation task across sessions.

Analysis of only session 2 and session 6 data failed to show significant main effects, but the interaction was significant, $F(1,10) = 5.192, p = .046$. An arcsine transformation was applied to the error rates from sessions 2 and 6 to stabilize the variance (Kleinbaum, et al., 1998), and the transformed data were analyzed with a repeated measures ANOVA. This analysis did not show a reliable effect of trial type, $F(1,10) = .574, p = .466$. During session 2, participants responded correctly to the VG task for 95.4% of the dual-task trials and 96.5% of the single-task trials. During session 6, participants responded correctly to 97.1% of the dual-task trials and 97.3% of the single-task trials.

3.5 Session 6 and Session 7

Telling participants to down-regulate or maintain negative emotions failed to produce any reliable effects on tracking RMSE (see Figure 5). The interaction between condition and session, $F(1,10) = .004, p = .950$, the interaction between condition and

secondary task, $F(2,20) = 1.013$, $p = .381$, and the three-way interaction of condition, session and secondary task, $F(2,20) = .583$, $p = .567$, were not statistically significant.

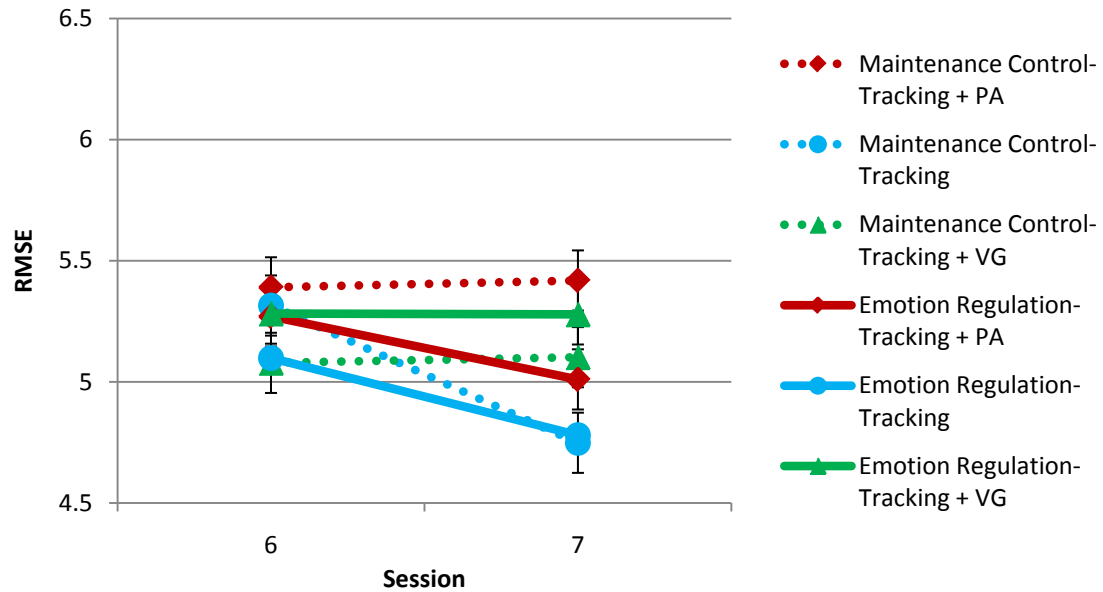


Figure 5: Tracking Data for the Maintenance Control and Emotion Regulation Groups for Session 6 and Session 7.
Root mean square error for the tracking task.

Moving beyond the between groups variable, repeated measures ANOVAs on session 6 and session 7 data showed a statistically significant effect of session on PA RT, $F(1,9) = 10.331$, $p = .011$ (see Figure 6 and Table 1), but no reliable effects on tracking RMSE, PA accuracy, VG RT, or VG accuracy. Participants responded more slowly to the PA task during session 7 than during the emotionally neutral session 6.

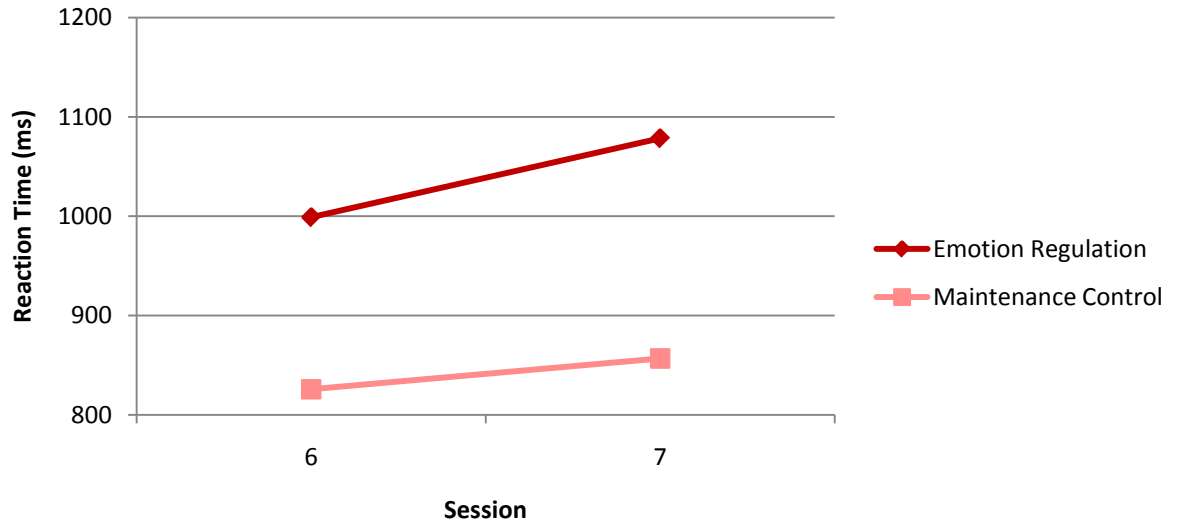


Figure 6: Paired Associate Reaction Time Data for Session 6 and Session 7.

Mean RTs to the film-related words in the PA task (i.e., *child, dirt, road, wound*) were compared with RTs to the unrelated words (i.e., *lamb, pear, seed, vest*) during sessions 6 and 7, but the factors (session and word relatedness) did not reliably interact, $F(1,9) = 2.052$, $p = .186$. Within the VG task, nouns that were related to the film clip did not elicit RTs significantly different from unrelated nouns (see Table 1).

Table 1: Mean Reaction Time Data for Verbal Tasks.

Reaction times to nouns related and unrelated to the film for sessions 6 and 7 for the paired associate task and session 7 of the verb generation task.

	PA	PA	VG
	Session 6	Session 7	Session 7
Related	908	977	1809
Unrelated	876	922	1770

The mostly null results of session 7 may suggest that the manipulations of anger and the instructions were ineffective, but the self report data suggest otherwise. Anger ratings taken immediately after the film (but before the instructions) were reliably greater than ratings taken immediately before, $F(1,9) = 27.026, p = .001$ (see Figure 7). For unexplained reasons, time (pre-film, post-film) interacted with condition (emotion regulation, maintenance control), $F(1,9) = 12.774, p = .006$, even though the conditions were identical at the time of the reports. Although the groups were counterbalanced for age and gender (in addition to tracking performance), the emotion regulation group reported larger increases in anger after the film than the maintenance control group.

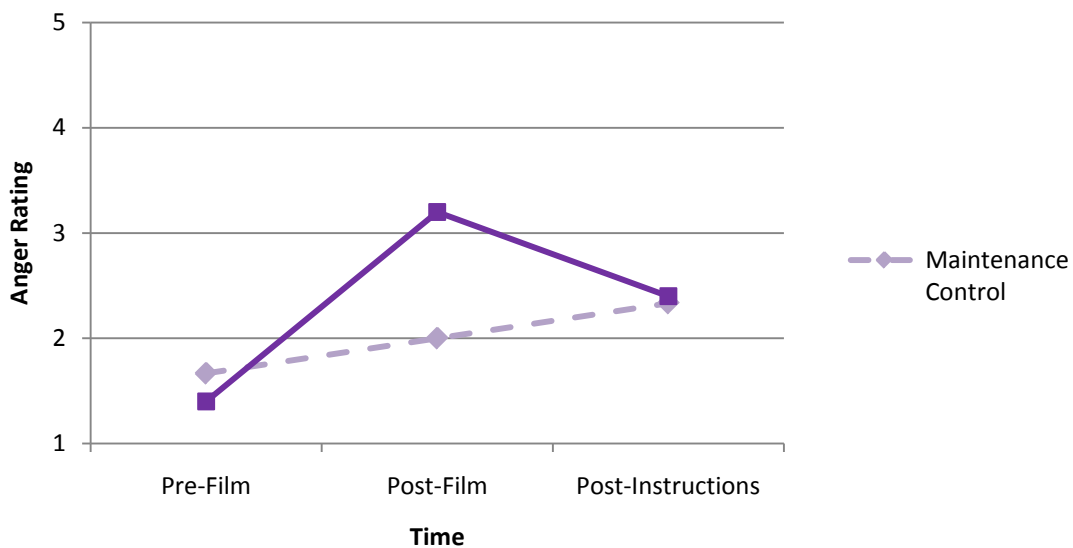


Figure 7: Self Report Data in Session 7.

Mean anger self reports before watching the film, after watching the film, and after hearing instructions.

After instructing participants to down-regulate or maintain negative emotions, their ratings suggested compliance with the instructions (see Figure 7). Time (post-film,

post-instructions) interacted significantly with condition, $F(1,9) = 7.628, p = .022$. The emotion regulation group reported marginally reduced anger, $F(1,4) = 4.571, p = .099$, while the maintenance control group's ratings did not significantly change.

CHAPTER 4

DISCUSSION

A paired associate task and a verb generation task individually impaired performance on a pursuit tracking task after 1 session of practice; however, dual-task interference to tracking performance was eliminated by 6 sessions of practice. Concerning performance on the verbal tasks, the pursuit tracking task slowed reaction times in the PA and VG tasks throughout sessions 5 and 6. Inducing anger with a film clip during session 7 did not lead to changes in the tracking and VG tasks but did lead to slower RTs in the PA task. Participants showed no differences in performance in session 7 whether they down-regulated or maintained negative emotions caused by the unpleasant film clip.

During session 2, both the PA and VG tasks impaired tracking performance. These results are consistent with one session dual-task studies that use easy tasks to represent driving and cell phone conversation (e.g., Strayer & Johnston, 2001). By session 3, the VG task continued to interfere with tracking performance, but participants were able to perform the PA task without tracking interference. In other words, VG-related interference to the tracking task remained longer than PA-related interference. This is consistent with the prediction that an information-generating verbal task would interfere with pursuit tracking more than a simpler word pair verbal task.

During sessions 4 through 6, neither of the secondary verbal tasks interfered with tracking performance. These results suggest that people can successfully perform a practiced continuous task without interference from a practiced verbal task. This is

partially consistent with Shinar et al. (2005), who found that 5 sessions of practice greatly reduced, but did not eliminate, dual-task interference on a driving task. However, Shinar and colleagues used a high fidelity driving simulator and used multiple dependent variables to assess driving performance, including average speed, speed variance, and average lane position. The task of keeping a mouse cursor aligned with a moving target was likely mastered more easily.

The successful elimination of dual-task interference on the tracking task raises an important question: How was the interference eliminated? It is well-known that practice can lead to a task being performed more quickly, more accurately, and with less susceptibility to interference from other tasks. However, information processing theorists frequently disagree over how these changes are facilitated. Some theorists (e.g. Logan, 1988; Shiffrin & Schneider, 1977) argue that performance on a novel task is mediated by capacity-limited control processes, whereas performance on a well-practiced task is mediated by mostly automatic processes that are not capacity-limited. That is, practice facilitates a qualitative shift from slow, capacity-limited performance to automatic performance. On the other hand, some theorists (e.g., Newell & Rosenbloom, 1980) argue that practice changes the efficiency but not the functional organization of control processes needed for task performance. That is, practice facilitates a quantitative shift from less to more efficient processing.

The elimination of dual-task interference on the tracking task seems, at first, to favor a qualitative change. After moderate practice, participants made frequent vocal responses to an auditory task without interfering with a continuous visual-manual task. Practice may have facilitated a transformation from declarative to procedural knowledge,

thereby allowing central processing stages of the tasks to operate in parallel (Meyer & Kieras, 1997a, 1997b, 1999; Schumacher, et al., 2001). Alternatively, practice may have allowed one or more of the tasks to become automatized, thereby making it possible to bypass the capacity-limited central stages of processing (Logan, 1988). Either way, processing would have been fundamentally reorganized.

However, there are reasons to doubt this account of qualitative shift. Although a tracking task appears continuous, some theorists (e.g., Craik, 1947; Pashler, 1998) have argued that tracking elicits intermittent reactions (about two per second) to correct for error in the position of the cursor. If pursuit tracking can be performed with a series of discrete stages, it is possible that central processing for the two tasks did not occur in parallel or automatically. Instead, a quantitative shift may have occurred, making processing more efficient, but not fundamentally different, from novice performance. This could be explained by the Stage Shortening hypothesis, which would posit that central processing on practiced tasks is faster but still serial (Byrne & Anderson, 2001; Ruthruff, Van Selst, Johnston, & Remington, 2006). Ruthruff and colleagues suggest that practice can reduce the time of the central processing stages to the extent that the central stages of multiple tasks no longer overlap. Thus two tasks can be performed simultaneously without interference, but central processing remains serial.

A qualitative or quantitative shift caused by practice presents problems for many one-session driving and cell phone studies. Evidence that cell phone conversation impairs driving performance often comes from studies in which participants perform easy but unpracticed tasks to represent driving and cell phone conversations (e.g., Strayer & Johnston, 2001; Wester, et al., 2008). These techniques are sufficient to answer specific

questions about cognitive and motor control, but generalizing the results to real world driving behavior may be inappropriate. One cannot assume that interference to an easy novice task is fundamentally equivalent to interference to a multifaceted, well-practiced task.

Although this study was primarily concerned with the effects of verbal tasks on tracking performance, the verbal task data themselves have interesting implications. For example, dual-task costs to PA performance persisted throughout sessions 2 through 6. That is, participants responded more slowly to PA stimuli during blocks in which they also performed the tracking task than blocks in which they performed the PA task alone. Participants were also less accurate during the dual-task blocks, which suggests that dual-task interference in the PA task did not result from a speed-accuracy tradeoff. It is noteworthy that dual-task interference was overcome in the tracking but not paired associate performance. Because the participants were told that the tracking task was more important, perhaps they learned to schedule their vocal and manual responses in a way that prioritized the primary task.

The effects of practice on verb generation performance are less straightforward. For sessions 2 and 3, VG task RTs were faster during dual-task blocks than single-task blocks. After session 4, single-task RTs became faster than dual-task RTs. This shift in VG task performance was accompanied by the disappearance of dual-task interference to the tracking task. Perhaps participants found the VG task especially difficult in the early sessions. The task itself is less constrained than the tracking and PA tasks, and it demands more use of long-term memory (viz., to retrieve semantically related verbs). Perceived difficulty of the VG task accounts well for the large costs to tracking performance seen in

sessions 2 and 3. After becoming more comfortable with the task through practice, the participants may have become better able to schedule their responses in a way that prioritized the primary tracking task.

The disappearance of dual-task interference on the tracking task but not the verbal tasks suggests that the participants actively used strategies to maximize performance. The strategy for the PA task stayed constant across sessions; interference to the tracking task disappeared fairly early in practice, whereas interference to the PA task remained. The VG task data suggest a strategy shift. Early in practice, participants prioritized the VG task which interfered with the tracking task. Later in practice, they were able to prioritize the tracking task which interfered with the VG task.

These shifts in performance over the course of practice are well accounted for by cognitive architectures such as Executive-Process/Interactive Control (EPIC; Meyer & Kieras, 1997a, 1997b, 1999; Meyer, et al., 1995) and Adaptive Control of Thought: Perceptual Motor (ACT-R/PM; Byrne & Anderson, 2001). According to EPIC, the individual develops Adaptive Executive Control (AEC), in which executive processes control the course of secondary task processing stages (Meyer & Kieras, 1997a, 1997b, 1999). Thus processing stages for the tracking and verbal tasks can be organized in a way that optimizes tracking performance.

AEC models may not account as well for the remaining dual-task interference to the verbal tasks. AEC models predict that perfect time sharing between two well-practiced tasks is possible when stimuli and responses use different modalities (Meyer & Kieras, 1997a, 1997b; Schumacher, et al., 2001). The interference of the visual-manual tracking task to the auditory-vocal verbal tasks might be better explained by ACT-R/PM.

This architecture's perceptual-motor modules run parallel with each other, but response selection at the central cognition level is serial.

However, the absence of perfect time sharing might also be explained by the instructions to prioritize the tracking task, as opposed to serial response selection constraints. Schumacher and colleagues (2001) have shown that individuals can achieve perfect time sharing with well-practiced, modality compatible tasks when instructed to give the tasks equal priority. They were then able to reintroduce dual-task interference in a group of practiced participants by putting the tasks in a context that encouraged task prioritization. Therefore, AEC cannot be discarded as a possible explanation. Participants may have developed and adapted their control strategies in a way that complimented the instructions to prioritize tracking, as opposed to a way that would result in perfect time sharing.

In session 7, participants watched an anger-inducing film clip before performing the tracking and verbal tasks. Dual-task interference reemerged in tracking performance; participants showed less tracking error during single-task tracking blocks than dual-task *tracking-VG* blocks. This implies that emotion may affect tracking performance when paired with an information-generating verbal task. However, the effect of emotion on tracking might be spurious. Comparisons of tracking performance between sessions 6 and 7 revealed no significant differences.

Participants received instructions to either down-regulate or maintain any negative emotions caused by the film, but the instructions had no effect on performance. This is inconsistent with evidence that emotion regulation impairs young adults on other tasks (e.g., Scheibe & Blanchard-Fields, 2009), which raises questions concerning the

effectiveness of the instruction manipulation. However, the self report data suggest that the manipulation worked. Participants indicated increased anger after seeing the film clip and before receiving instructions. After being told to down-regulate or maintain negative emotions caused by the film, the emotion regulation group reported marginally less anger and the maintenance control group reported sustained levels of anger.

Assuming participants followed the emotion regulation instructions, the complete absence of effects suggests that people can regulate emotion without interference to practiced visual tracking and auditory verbal tasks. This may suggest that cognitive control and emotion control rely on separate processes. That is, cognitive and emotion control do not interfere with one another because they do not compete for the same resources. This idea is inconsistent with the Ego Depletion hypothesis (Baumeister, Bratslavsky, et al., 1998), which posits that the energy required in a variety of the self's operations is taken from a single, limited source. Thus an individual's ability to down-regulate an emotion will directly compete with that individual's ability to perform information processing and perceptual-motor tasks.

Another explanation for the lack of interference created by the emotion regulation goal relies on the previously discussed differences between novice and practiced performance. Before the qualitative and quantitative shifts in processing, novice performance may rely heavily on general purpose control processes. Two novel tasks with different input and output modalities (i.e., an AV task and a VM task) will interfere with one another if performed simultaneously, because both tasks are competing for the same amodal resources (Anderson, 1996).

After sufficient practice, performance may rely on modality-specific control processes. The AV and VM tasks will no longer interfere with each other, because the tasks will demand control processes depending on their respective modalities. This can explain why participants were able to down-regulate their emotions while performing the perceptual-motor tasks. The energy needed for emotion regulation may have come from a general purpose source, but the control needed for the practiced perceptual-motor tasks was modality-specific. Thus the required control processes did not overlap.

This study attempted to address issues that often go ignored in driving research, such as practice effects and emotion, but there were many limitations. Although some tentative inferences can be made about emotion regulation and its effects on easy, practiced perceptual-motor tasks, this study did not successfully address the effects of emotion regulation on driving. The pursuit tracking task poorly represents the multi-faceted behavior of driving. Therefore, the results cannot be generalized to research that uses actual traffic or high-quality driving simulators, only research that uses easy laboratory tasks as proxies for driving.

The driving subtask most similar to the pursuit tracking task is arguably steering/lane keeping. Some meta-analyses have reported that variables like driving speed and braking reaction time are more sensitive to cell phone interference than lane keeping (Horrey & Wickens, 2006). It is possible that participants would not have eliminated dual-task interference if the tracking task had been paired with a visual-manual RT task to represent braking.

The sample size ($N = 12$) provided enough power for most of the within-subject variables of this study, but is too small to draw inferences for the between-subject

variable (emotion regulation or maintenance control instructions). The sample size was not increased because no trends emerged from the 12 participants to suggest any differences between the instruction groups.

Plans for future research include investigating the effects of emotion regulation on unpracticed pursuit tracking and verbal tasks. It is predicted that, after only one session of practice, participants instructed to down-regulate negative emotions will perform more poorly than participants instructed to maintain any negative emotions because both tasks may rely on general purpose control.

Driving a car is a usually well-practiced task that demands attention to multiple stimuli (e.g., lane position, other cars, traffic lights) as well as many motor responses (e.g., steering, accelerating, braking). Conversely, a pursuit tracking task like the one used in this study is easy but novel to most individuals. Adding a secondary task to either of these will likely impair performance, but this does not imply that the interference to those tasks is the same. A complicated, well-practiced task is fundamentally different from an easy, unpracticed task.

Although the participants were able to eliminate dual-task interference with practice, the results are not evidence that people can safely drive while talking on a cell phone. Most motorists have extensive practice performing both activities simultaneously, yet epidemiological research of driving behavior suggests that the two cannot be performed together safely. This discrepancy between these data and the results of this study raises serious doubts about the ecological validity of using easy laboratory tasks to represent driving behavior.

REFERENCES

- Abramowitz, J. S., Tolin, D. F., & Street, G. P. (2001). Paradoxical effects of thought suppression: A meta-analysis of controlled studies. *Clinical Psychology Review*, 21(5), 683-703.
- Administration, N. H. T. S. (1998). *Unsafe Driving Behaviors Questionnaire*.
- Alm, H., & Nilsson, L. (1994). Changes in driver behavior as a function of handsfree mobile phones: A simulator study. *Accident Analysis and Prevention*, 26(4), 441-451.
- Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone task on driver behavior in a car following situation. *Accident Analysis and Prevention*, 27(5), 707-715.
- Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review*, 89(4), 369-406.
- Anderson, J. R. (1993). *Rules of the mind*. Hillsdale, NJ: Erlbaum.
- Anderson, J. R. (1996). *ACT - A simple theory of complex cognition*.
- Baumeister, R. F. (2005). Strangers to ourselves: Discovering the adaptive unconscious. *Journal of Social and Clinical Psychology*, 24(2), 293-295.
- Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology*, 74(5), 1252-1265.
- Baumeister, R. F., Dale, K., & Tice, D. M. (1998). *Replenishing the self: Effects of positive affect on performance and persistence following ego depletion*. Case Western Reserve University, Cleveland, OH.
- Baumeister, R. F., & Heatherton, T. F. (1996). Self-regulation failure: An overview. *Psychological Inquiry*, 7(1), 1-15.
- Baumeister, R. F., Heatherton, T. F., & Tice, D. M. (1994). *Losing control: How and why people fail at self-regulation*. San Diego: Academic.
- Baumeister, R. F., Muraven, M., & Tice, D. M. (2000). Ego depletion: A resource model of volition, self-regulation, and controlled processing. *Social Cognition*, 18(2), 130-150.

- Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science*, 16(6), 351-355.
- Boase, M. (1988). *Sorry can't talk - just overtaking a lorry. The definition and experimental investigation of the problem of driving and handsfree carphone use*. Loughborough University of Technology.
- Bovair, S., & Kieras, D. E. (1991). Toward a model of acquiring procedures from text. In R. Barr, M. L. Kamil, P. Mosenthal & P. D. Pearson (Eds.), *Handbook of reading research* (Vol. 2, pp. 206-229). New York: Longman.
- Briem, V., & Hedman, L. R. (1995). Behavioural effects of mobile telephone use during simulated driving. *Ergonomics*, 38(12), 2536-2562.
- Briley, J., & Woods, D. (Writer). (1987). Cry Freedom. In R. Attenborough, J. Briley, N. Spencer & T. A. Clegg (Producer). United Kingdom: Universal Pictures.
- Brookhuis, K. A., Devries, G., & Dewaard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention*, 23(4), 309-316.
- Brown, I. D., Tickner, A. H., & Simmonds, D. C. (1969). Interference between concurrent tasks of driving and telephoning. *Journal of Applied Psychology*, 53(5), 419-&.
- Byrne, M. D., & Anderson, J. R. (2001). Serial modules in parallel: The psychological refractory period and perfect time-sharing. *Psychological Review*, 108(4), 847-869.
- Caird, J., Scialfa, C. T., Ho, G., & Smiley, A. (2004). *Effects of cellular telephones on driving behaviour and crash risk: Results of meta-analysis*: CAA Foundation for Traffic Safety.
- Center for Disease Control. (2005). Unintentional Injuries. Retrieved 9-15, 2008, from http://webappa.cdc.gov/cgi-bin/broker.exe?_service=v8prod&_server=app-v-ehip-wisq.cdc.gov&_port=5081&_sessionid=tE9wJDAwK52&_program=wisqars.details10.sas&_service=&type=U&prtfmt=STANDARD&age1=.&age2=.&agegp=AllAges&deaths=117809&_debug=0&lcdfmt=lcd1ageðncty=0&ranking=10&deathle=Death.
- Craik, K. W. J. (1947). Theory of the human operator in control systems. I. The operator as an engineering system. *British Journal of Psychology*, 38, 56-61.
- Deffenbacher, J. L., Oetting, E. R., Lynch, R. S., & Morris, C. D. (1996). The expression of anger and its consequences. *Behaviour Research and Therapy*, 34(7), 575-590.

- Dressel, J., & Atchley, P. (2008). Cellular phone use while driving: A methodological checklist for investigating dual-task costs. *Transportation Research Part F-Traffic Psychology and Behaviour*, 11(5), 347-361.
- Faircloth, S. H., Ashby, M. C., Ross, T., & Parkes, A. M. (1991). Paper presented at the ISATAS International Symposium on Automotive Technology and Automation, Florence.
- Fastenmeier, W., & Gstalter, H. (2007). Driving task analysis as a tool in traffic safety research and practice. *Safety Science*, 45, 952-979.
- Gallacher, J. E. J., Yarnell, J. W. G., Sweetnam, P. M., Elwood, P. C., & Stansfeld, S. A. (1999). Anger and incident heart disease in the caerphilly study. *Psychosomatic Medicine*, 61(4), 446-453.
- Govenors Highway Safety Administration. (2008). Cell phone and driving laws. *State Info and Laws* Retrieved 10-24, 2008, from http://www.ghsa.org/html/stateinfo/laws/cellphone_laws.html.
- Green, M. J., & Malhi, G. S. (2006). Neural mechanisms of the cognitive control of emotion. *Acta Neuropsychiatrica*, 18(3-4), 144-153.
- Gross, J. J. (1998). Antecedent- and response-focused emotion regulation: Divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology*, 74(1), 224-237.
- Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology*, 39(3), 281-291.
- Gross, J. J., & Levenson, R. W. (1995). Emotion elicitation using films. *Cognition and Emotion*, 9(1), 87-108.
- Gross, J. J., & Levenson, R. W. (1997). Hiding feelings: The acute effects of inhibiting negative and positive emotion. *Journal of Abnormal Psychology*, 106(1), 95-103.
- Haigney, D., & Westerman, S. J. (2001). Mobile (cellular) phone use and driving: a critical review of research methodology. *Ergonomics*, 44(2), 132-143.
- Harbluk, J. L., Noy, Y. I., & Eizenman, M. (2002). *Impact of cognitive distraction on driver visual behaviour and vehicle control*. Paper presented at the 81st annual meeting of the Transportation Research Board, Washington, D.C.
- Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. *Accident Analysis and Prevention*, 39(2), 372-379.

- Hazeltine, E., & Ruthruff, E. (2006). Modality pairing effects and the response selection bottleneck. *Psychological Research-Psychologische Forschung*, 70(6), 504-513.
- Hazeltine, E., Ruthruff, E., & Remington, R. W. (2006). The role of input and output modality pairings in dual-task performance: Evidence for content-dependent central interference. *Cognitive Psychology*, 52(4), 291-345.
- Hazeltine, E., Teague, D., & Ivry, R. B. (2002). Simultaneous dual-task performance reveals parallel response selection after practice. *Journal of Experimental Psychology-Human Perception and Performance*, 28(3), 527-545.
- Hewig, J., Hagemann, D., Seifert, J., Gollwitzer, M., Naumann, E., & Bartussek, D. (2005). A revised film set for the induction of basic emotions. *Cognition & Emotion*, 19(7), 1095-1109.
- Horrey, W. J., & Wickens, C. D. (2006). Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors*, 48(1), 196-205.
- Hosie, J. A., Milne, A. B., & McArthur, L. (2005). The after-effects of regulating anger and anger-related emotions on self-report ratings and behavior: Divergent consequences for men and women. *Psychologia*, 48(4), 288-305.
- Hunt, E. (1978). Mechanics of Verbal-Ability. *Psychological Review*, 85(2), 109-130.
- Ishida, T., & Matsuura, T. (2001). The effect of cellular phone use on driving performance. *IATSS Res*, 25(2), 6-14.
- Just, M. A., Keller, T. A., & Cynkar, J. (2008). A decrease in brain activation associated with driving when listening to someone speak. *Brain Research*, 1205, 70-80.
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.
- Kleinbaum, D. G., Kupper, L. L., Muller, K. E., & Nizam, A. (1998). Applied regression analysis and other multivariate methods.
- Lebiere, C., & Anderson, J. R. (1998). Cognitive arithmetic. In J. R. Anderson & C. Lebiere (Eds.), *The atomic components of thought* (pp. 297-342). Mahwah, NJ: Erlbaum.
- Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, 95(4), 492-527.
- McCarley, J. S., Vais, M. J., Pringle, H., Kramer, A. F., Irwin, D. E., & Strayer, D. L. (2004). Conversation disrupts change detection in complex traffic scenes. *Human Factors*, 46(3), 424-436.

- McCartt, A. T., Hellinga, L. A., & Bratiman, K. A. (2006). Cell phones and driving: review of research. *Traffic Inj Prev*, 7(2), 89-106.
- McCleod, P. (1977). Parallel processing and the psychological refractory period. *Acta Psychologica*, 41, 381-391.
- McKnight, A. J., & McKnight, A. S. (1993). The Effect of Cellular Phone Use upon Driver Attention. *Accident Analysis and Prevention*, 25(3), 259-265.
- Meyer, D. E., & Kieras, D. E. (1997a). A computational theory of executive cognitive processes and multiple-task performance .1. Basic mechanisms. *Psychological Review*, 104(1), 3-65.
- Meyer, D. E., & Kieras, D. E. (1997b). A computational theory of executive cognitive processes and multiple-task performance .2. Accounts of psychological refractory-period phenomena. *Psychological Review*, 104(4), 749-791.
- Meyer, D. E., & Kieras, D. E. (1999). Precis to a practical unified theory of cognition and action: Some lessons from EPIC computational models of human multiple-task performance *Attention and Performance Xvii* (Vol. 17, pp. 17-88).
- Meyer, D. E., Kieras, D. E., Lauber, E., Schumacher, E. H., Glass, J., Zurbriggen, E., et al. (1995). Adaptive executive control: Flexible multiple-task performance without pervasive immutable response-selection bottlenecks. *Acta Psychologica*, 90(1-3), 163-190.
- Mourant, R. R., & Rockwell, T. H. (1972). Strategies of Visual Search by Novice and Experienced Drivers. *Human Factors*, 14(4), 325-&.
- Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology*, 74(3), 774-789.
- Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review*, 86, 214-255.
- Newell, A., & Rosenbloom, P. S. (1980). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive Skills and their Acquisition* (pp. 1-55). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Pashler, H. E. (1998). *The Psychology of Attention*. Cambridge, MS: MIT Press.
- Philippot, P. (1993). Inducing and assessing differentiated emotion-feeling states in the laboratory. *Cognition & Emotion*, 7(2), 171-193.

- Pizzighello, S., & Bressan, P. (2008). Auditory attention causes visual inattention blindness. *Perception*, 37(6), 859-866.
- Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information Processing and Cognition: The Loyola Symposium*. Hillsdale, NJ: Erlbaum.
- Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: Effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology-Applied*, 9(2), 119-137.
- Redelmeier, D. A., & Tibshirani, R. J. (1997). Association between cellular-telephone calls and motor vehicle collisions. *New England Journal of Medicine*, 336(7), 453-458.
- Richards, J. M. (2004). The cognitive consequences of concealing feelings. *Current Directions in Psychological Science*, 13(4), 131-134.
- Richards, J. M., & Gross, J. J. (2000). Emotion regulation and memory: The cognitive costs of keeping one's cool. *Journal of Personality and Social Psychology*, 79(3), 410-424.
- Ruthruff, E., Hazeltine, E., & Remington, R. W. (2006). What causes residual dual-task interference after practice? *Psychological Research-Psychologische Forschung*, 70(6), 494-503.
- Ruthruff, E., Johnston, J. C., Van Selst, M., Whitsell, S., & Remington, R. (2003). Vanishing dual-task interference after practice: Has the bottleneck been eliminated or is it merely latent? *Journal of Experimental Psychology-Human Perception and Performance*, 29(2), 280-289.
- Ruthruff, E., Van Selst, M., Johnston, J. C., & Remington, R. (2006). How does practice reduce dual-task interference: Integration, automatization, or just stage-shortening? *Psychological Research-Psychologische Forschung*, 70(2), 125-142.
- Salvucci, D. D., & Macuga, K. L. (2002). Predicting the effects of cellular-phone dialing on driver performance. *Cognitive Systems Research*, 3, 95-102.
- Sanders, A. F. (1980). Stage analysis of reaction processes. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 331-354). Amsterdam: North-Holland.
- Scheibe, S., & Blanchard-Fields, F. (2009). Effects of Regulating Emotions on Cognitive Performance: What Is Costly for Young Adults Is Not So Costly for Older Adults. *Psychology and Aging*, 24(1), 217-223.

- Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime User's Guide*. Pittsburgh: Psychology Software Tools, Inc.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review*, 84, 1-66.
- Schumacher, E. H., Hendricks, M. J., & D'Esposito, M. D. (2005). Sustained involvement of a frontal-parietal network for spatial response selection with practice of a spatial choice-reaction task. *Neuropsychologia*, 43(10), 1444-1455.
- Schumacher, E. H., Seymour, T. L., Glass, J. M., Fencsik, D. E., Lauber, E. J., Kieras, D. E., et al. (2001). Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck. *Psychological Science*, 12(2), 101-108.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, 84, 127-190.
- Shinar, D., Meir, M., & Ben-Shoham, I. (1998). How automatic is manual gear shifting? *Human Factors*, 40(4), 647-654.
- Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis and Prevention*, 37(2), 315-326.
- Shiota, M. N., & Levenson, R. W. (2008). *Normal aging and the effectiveness of reappraisal-based emotion regulation*. Unpublished manuscript.
- Simons, D. J. (2000). Attentional capture and inattention blindness. *Trends in Cognitive Sciences*, 4(4), 147-155.
- Smallen, D. (2004). National Household Travel Survey. Retrieved 10-8, 2008, from http://www.bts.gov/press_releases/2004/bts010_04/html/bts010_04.html.
- Stein, A. C., Parseghian, Z., & Allen, R. W. (1987). *A simulator study of the safety implications of cellular mobile phone use*. Paper presented at the 31st Annual American Association for Automotive Medicine, Hawthorne, CA.
- Sternberg, S. (1969). Discovery of processing stages - Extensions of Donders method. *Acta Psychologica*, 30, 276-+.
- Strayer, D. L., & Drews, F. A. (2007). Cell-phone-induced driver distraction. *Current Directions in Psychological Science*, 16(3), 128-131.

- Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology-Applied*, 9(1), 23-32.
- Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science*, 12(6), 462-466.
- Thompson, R. A. (1994). Emotion regulation: A theme in search of a definition. *Monographs of the Society for Research in Child Development*, 59(2/3), 25-52.
- Tombu, M., & Jolicoeur, P. (2003). A central capacity sharing model of dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, 29(1), 3-18.
- Venable, V. L., Carlson, C. R., & Wilson, J. (2001). The role of anger and depression in recurrent headache. *Headache*, 41(1), 21-30.
- Wester, A. E., Bockner, K. B. E., Volkerts, E. R., Verster, J. C., & Kenemans, J. L. (2008). Event-related potentials and secondary task. performance during simulated driving. *Accident Analysis and Prevention*, 40(1), 1-7.
- Wickens, C. D. (1980). The structure of attentional resources. In R. Nickerson (Ed.), *Attention and performance VIII* (pp. 239-257). Hillsdale: Erlbaum.
- Wickens, C. D. (1991). Processing resources and attention. In D. L. Damos (Ed.), *Multiple-task Performance* (pp. 3-34): CRC Press.
- Wilson, M. D. (1988). The MRC Psycholinguistic Database: Machine Readable Dictionary, Version 2. *Behavioural Research Methods, Instruments and Computers*, 20(1), 6-11.